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Product inspection policy for an imperfect production system with inspection errors and warranty cost

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ABSTRACT

During manufacturing of products, all produced items are considered as perfect in general. This viewpoint of taking all finished products are perfect is not correct always. Defective items may occur during the production process for several reasons. This paper describes a deteriorating production process which randomly shifts to *out-of-control* state from *in-control* state. In case of full inspection policy, expected total cost together with inspection cost results higher inventory cost. Therefore, product inspection policy is better to use for reducing inspection costs. During product inspection process, inspectors may choose falsely a defective item as non-defective and vice-versa. Type I and Type II errors are incorporated in this model to make more realistic rather than existing models. This model includes a warranty policy for some fixed time periods. Some numerical examples, sensitivity analysis, and graphical representations are given to illustrate this model.

1. Introduction

For any manufacturing industry, the minimization of cost is a major consideration with product's quality. High quality products always lead to a higher cost and in-turn low quality products result to a lower cost. It is quite natural that manufactures decide the product's quality by product inspection policy. During the process inspection policy, inspection cost needs much attention which indicates the increasing value of labor cost. To reduce inspection cost, instead of full inspection policy, only product inspection policy is utilized. For this inspection policy, defective products are detected easily with lower inspection cost. The aim of this inspection policy is to determine any quality defects that would prevent shipment of poor products. By utilizing this product inspection policy, shipments cost can be minimized by avoiding the dispatch of any imperfect quality products. Chryssolouris and Patel (1987) discussed the production process where imperfect items are detected through product inspection policy. Kim and Hong (1999) considered an economic manufacturing quantity (EMQ) model in an imperfect process which describes a random deterioration from an *in-control* state to an *out-of-control* state with an arbitrary distribution and some defective items. Wang and Sheu (2001) described the relationship between production, inventory, and inspection in a deteriorating production system. Chryssolouris (2006) developed several quality related issues for the process control. Previous research work with offline inspection policy of products was extended by Wang and Meng (2009). Bendavid and Herer (2009) introduced an optimal policy that obtains the number of units to inspect and the number of disposal units to minimize the expected cost. Hassan and Diab (2010) incorporated a visual inspection approach that can be used on line to test simultaneously multiple qualities characteristics. Based on tolerance bands of each characteristic, an index is experimentally developed to reflect the deviation of a quality characteristic dimension from its nominal value. Sarkar, Sana, and Chaudhuri (2010) formulated an optimal production lot size, safety stock, and reliability parameter where the production facility is subject to random breakdown of machinery system. They generalized the model with preventive and corrective maintenance, safety stock for repair items, and shortages. Laofor and Peansupap (2012) surveyed an innovative system for defective detection and quantification that able to augment for visual quality inspections. Chen (2013) formulated the integrated problem of production, preventive maintenance (PM), and inspection in an imperfect production process where rework and PM errors exist. Baudet, Maire, and Pillet (2013) described how a sensory analysis test can be applied for the visual inspection of product surface.

The basic economic production quantity (EPQ) model assumes that all produced items are perfect. But it is almost impossible for any production system because of long-run production process. Imperfect quality or poor items may be produced during long-run

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production system. During production, the system may transfer to *out-of-control* state from *in-control* state at any random time. Thus, producing items are not always perfect. Generally it depends on the condition of production process. Usually, when the production process starts, the machine is *in-control* state and items produced are near about 100 percent perfect quality. After sometimes, it transfers to *out-of-control* state and produces defective products. In this direction, (Porteus, 1986) discussed about process quality by reducing the probability of the process moved to *out-of-control* state. Rosenblatt and Lee (1986) modeled the variable proportion of defective items for linear, exponential, and multi-state deteriorating processes. Tseng, Yeh, and Ho (1998) examined several maintenance policies for deteriorating production systems. Ben-Daya (2002) derived an integrated model for joint determination of economic production quantity and preventive maintenance (PM) level in an imperfect process with increasing hazard rate. Chung and Hou (2003) developed a production model to obtain an optimal run time for a deteriorating production system with allowable shortages. Lee (2005) investigated an imperfect production system with imperfect product quality and supplied quantity. Lin, Chiu, and Ting (2008) discussed an algebraic approach to replace the use of calculus on the cost function as well as long-run average production-inventory costs in an imperfect EMQ model. Liao, Chen, and Sheu (2009) extended previous works by assuming a deteriorating production system with increasing hazard rate: imperfect repair and rework upon failure (*out-of-control* state). Ouyang and Chang (2013) discussed effects of reworking for imperfect quality items, trade-credit policy, and complete backlogging in an economic production quantity model. Tai (2013) developed two economic production quantity (EPQ) models for deteriorating/imperfect items with rework process. Sarkar and Moon (2014) established the relationship between quality improvement, reorder point, lead time, and backorder rate in an imperfect production process. Sarkar, Chaudhuri, and Moon (2014) surveyed an inventory model with improved quality and backorder price discount under controllable lead time.

Quality of any product can be obtained through product inspection policy by assuming 100 percent perfect inspection process. But in general, inspection process is not error free in reality as all machines are not allow 100 percent perfect inspections and human factors are involved. There may be a possibility of Type I error (falsely rejecting non-defective items) or Type II error (falsely accepting defective items) in any industry. Type I error generates when a perfect item is rejected and it implies manufacturer's risk. On the other hand, Type II error generates when the acceptance of an imperfect lot is considered and it implies customer's risk. It is also considered that cost of falsely accepted defective items is much greater than cost of falsely rejected non-defective items. Because, falsely accepted defective items in system may result system failure which causes loss of human lives. Raz and Bricker (1993) considered inspection errors during screening in an production process. Rentoul, Mullineux, and Medland (1994) studied several ways of inspection errors in manufacturing system which are made by comparing inspection points with a solid model of the desired component. Wang and Sheu (2003) determined an optimal production, inspection, and maintenance policy under the effect of process inspection errors. An inspection policy with two types of inspection errors to accept the economic production quantity for real world applications was considered by Wang (2007). An inventory model in an imperfect production process with the preventive maintenance and inspection errors was considered by Darwish and Ben-Daya (2007). Wang, Dohi, and Tsai (2010) considered a partial inspection approach over commonly used policies for both full and no inspection. Lin, Chen, and Chen (2011) investigated an imperfect production system for production lot size, maintenance, and quality with increasing hazard rates. Yoo, Kim, and Park (2012) obtained an optimal lot size in an imperfect production with inspection, customer return, and defective disposal. Hsu and Hsu (2013) developed an economic order quantity (EOQ) model with imperfect quality items, inspection errors, shortages, and sales returns. Cárdenas-Barrón, Sarkar, and Treviño Garza (2013) deduced an economic manufacturing quantity (EMQ) model for rework and multiple shipments. Sarkar, Gupta, Chaudhuri, and Goyal (2014) formulated an inventory model with inspection policy and variable lead time. Sarkar, Chaudhuri, and Moon (2014) discussed quality improvement of products and setup cost reduction for a continuous-review inventory model with a service level constraint. Sarkar, Cárdenas-Barrón, Sarkar, and Singgih (2014) obtained an inventory model by assuming random defective rates which follow three different distribution functions such as uniform, triangular, and beta.

Warranty period is the time period in which a sale out product provides satisfactory performance to the customer offered by the retailer. If any purchased product/sale out item failed to work within its warranty period, then the retailer replace it with a new item or repair one part or some parts of that product. Warranty cost or post sale cost includes repair cost, parts replacement cost, and labor cost. Chun and Tang (1995) developed an inventory model with the free-replacement and fixed-period warranty policy within a given warranty period. Monga and Zuo (1998) derived a problem on reliability based design of a series-parallel system by considering burn-in, warranty, and maintenance. Wang (2004) deduced an economic production quantity problem in an imperfect production process with a free-repair warranty policy. Wang (2005) described product-inspection policy for a deteriorating production system. Chen and Lo (2006) developed an imperfect production system with allowable shortages for products with free minimal repair warranty. Giri and Dohi (2007) described an inventory model under two different inspection policies: (i) no action is taken during a production-run unless the system is discovered in an *out-of-control* state by inspection and (ii) preventive repair action is undertaken once the *in-control* state of the process is detected by inspection. Darghouth, Chelbi, and Ait-kadi (2012) presented an analytical model taking into account the commitments of manufacturer and customer. The model gives some instants where the inspections are performed by considering the warranty period. See Table 1 for contribution of different authors.

This paper describes a production process in which the machinery system shifts from *in-control* state to *out-of-control* state at any random time. It is considered that once the system transfers to *out-of-control* state, it remains there until the production-run. The *out-of-control* state of the imperfect process follows a probabilistic distribution until the production stops. Defective items are detected through product inspection and are reworked at some fixed cost. On the other hand, non-inspected defective items are transported to the market for sale with warranty/post sale cost. This paper is formulated to minimize the expected total cost per item by the product inspection policy and production-run length. The orientation of the paper is as follows: In Section 2, notation and assumptions are discussed. The mathematical model is given in Section 3. In Section 4, some numerical examples and sensitivity analysis are presented to illustrate the model. Finally, conclusions and future extensions of this model are given in Section 5.

2. Notation and assumptions

The following notation are used to develop this model

Decision variables

t production-run length (unit time)
u non-inspected fraction in a batch ($0 \leq u \leq 1$) (units)

Parameters

d annual demand per unit time (units/unit time)
p production rate per unit time (units/unit time)
k setup cost for each production-run per setup (dollar/setup)